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MEMORANDUM

From: Bill Jemison
To: Dr. Daniel Tam, ONR
Date: 3/31/2012

Subject: Progress Report 006–
Chaotic LIDAR for Naval Applications: FY12 Q2 Progress Report (1/7/2012– 3/31/2012)

This document provides a progress report on the project "Chaotic LIDAR for Naval Applications" covering the period of 1/7/2012–3/31/2012.

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FY12 Q2 Progress Report: Chaotic LIDAR for Naval Applications

This document contains a **Progress Summary for FY12 Q2** and a **Short Work Statement for FY12 Q3**.

Progress Summary for FY12 Q2

A high power, wide bandwidth green optical signal is sought for LIDAR work in water. Previous reports have detailed the generation of wide bandwidth chaotic signals using fiber ring lasers. These signals have powers on the order of 10 mW, and they operate in the infrared, at 1550 nm and 1064 nm (previously, 1071 nm). For underwater work, these signals must be amplified and frequency doubled. This report details design and simulation of a high power frequency doubling circuit, which will both amplify the input wide bandwidth signal and frequency double it. This circuit is intended for use with the 1064 nm laser, to generate 500 mW of optical power at 532 nm, with 1 GHz flat, chaotic bandwidth.

High Power Frequency Doubling Circuit

The three-stage doubling circuit is shown in Figure 1. The fiber laser source is connected to a preamplifier stage, where the signal power is increased from 10 mW to 200 mW (13 dB gain) without signal distortion. The output of the preamplifier is fed through a polarization controller to enforce linear polarity. The signal then passes through a main gain stage, where high power pumping boosts the signal to 11 W (>17 dB gain). This high power signal then leaves the fiber and is focused down onto a second-harmonic generating (SHG) crystal. The output beam from this crystal contains high-intensity green light that can be used in underwater LIDAR.

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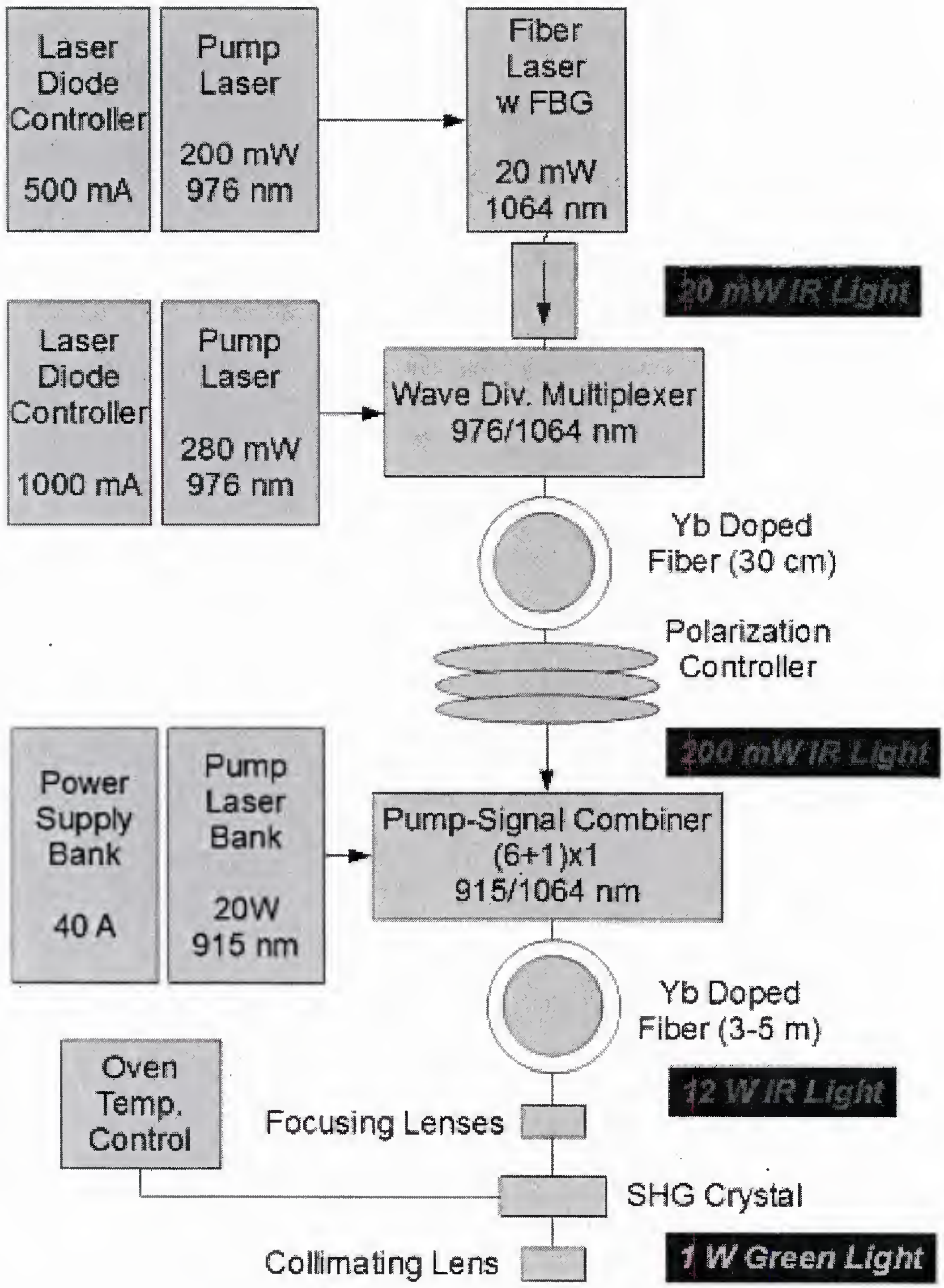

Figure 1. High power frequency doubling circuit. The 1064 nm wide bandwidth fiber laser source passes through a preamplifier, a gain amplifier, and a second-harmonic generating crystal, to produce the desired high-power green signal.

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In this design, the fiber laser is modified for better power and usable bandwidth. Pump power is increased to 200 mW, for a projected lasing power above 20 mW. A narrow, 0.1-nm fiber Braggs grating (FBG) is also included in the resonator, to concentrate power in an 18 GHz spectrum.

A single-mode pump and a wave-division multiplexer (WDM) are used to core-pump a short piece of doped fiber for the preamplifier. A simple forward-pumped arrangement using ~0.5 m of Yb-doped fiber is desirable for maximum output power, with minimum component losses. At the output of the preamplifier, the fiber is rotated on a three-paddle polarization controller that forces the polarization to be linear, as is optimal for SHG through the crystal.

The main gain stage is a cladding-pumped amplifier, using high-power, fiber-coupled laser semiconductor diodes to pump a multimode fiber. A pump-signal combiner handles mode matching between the passive pumped fiber, the signal fiber and the active double-clad Yb-doped fiber. The signal level at the end of the double-clad fiber will be 11-13 W, suitable for frequency doubling in the crystal. A series of free-space lenses collimate and focus the infrared beam as it exits the fiber. The beam is focused on the center of the SHG PPKTP crystal. This crystal has an efficiency of 0.8% per W of optical power when its temperature is controlled by a digital oven enclosure, so the green output will be on the order of 1 W. The output beam will be collimated for use in air or water.

Predicted Performance

Simulation of the fiber amplifiers predicts the signal gain through the active fiber, and allows comparison of alternative amplifier configurations. Active fiber simulation along the length of the fiber is based on the laser rate equations, with a time-independent calculation for upper state population.

$$\pm\frac{dP^{\pm}(z,\lambda)}{dz} = \Gamma[\sigma_e(\lambda)N_2 - \sigma_a(\lambda)N_1]P^{\pm}(z,\lambda) + \Gamma\sigma_e(\lambda)N_2(z)P_0(\lambda) - \alpha(z,\lambda)P^{\pm}(z,\lambda)) \quad (1)$$

$$\frac{N_2(z)}{N_{tot}} = \frac{\frac{(P_P^+(z) + P_P^-(z))\sigma_{ap}\Gamma_P}{h\upsilon_p A} + \frac{\Gamma_s}{hcA}\int \sigma_a(\lambda)[P^+(z,\lambda) + P^-(z,\lambda)]\lambda d\lambda}{\frac{(P_P^+(z) + P_P^-(z))(\sigma_{ap}+\sigma_{ep})\Gamma_P}{h\upsilon_p A} + \frac{1}{\tau} + \frac{\Gamma_s}{hcA}\int(\sigma_a(\lambda) + \sigma_e(\lambda))[P^+(z,\lambda) + P^-(z,\lambda)]\lambda d\lambda} \quad (2)$$

Using the input signal and pump powers as boundary conditions for this boundary value problem (BVP), the power and upper state population are computed along the fiber. Figure 2 shows the simulation results for the preamplifier, for a forward pumped single-pass configuration. Simulation parameters for the preamplifier are included in Table 1.

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Table 1. Preamplifier Simulation Parameters					
Parameter	**Symbol**	**Value**	**Parameter**	**Symbol**	**Value**
Fiber Laser Power	$P_S^{\pm}$	22 mW	Dopant Ion	-	Yb^{3+}
Fiber Laser Wavelength	λ_S	1064 nm	Doping Concentration	N	$80 \times 10^{24}\ m^{-3}$
Pump Power	$P_P^{\pm}$	280 mW	Dopant Host	-	ZBLAN
Pump Wavelength	λ_P	976 nm	Upper State Lifetime	τ	0.84 ms
ASE Wavelengths	λ	800 nm to 1200 nm	Absorption and Emission Cross-Sections	σ_a, σ_e	[1]
ASE Resolution	$d\lambda$	30 nm	Attenuation Coeff.	α	$0.003\ m^{-1}$
Fiber Size (MFD)	d	6 µm	Overlap Constant	Γ_P, Γ_S	0.95
Fiber Length	L	1 m			

Other values used in equations: c is the speed of light in the host; h is Planck's constant. Fiber area A and wave velocity υ are derived. MFD: Mode field diameter; ZBLAN: Heavy metal fluoride glass.
[1] Cross-section Gaussian model follows Marciante and Zuegel, H*igh-Gain, Polarization-Preserving Yb-Doped Fiber Amplifier for Low-Duty-Cycle Pulse Amplification,* Applied Optics Vol. 45, Issue 26, 2006.

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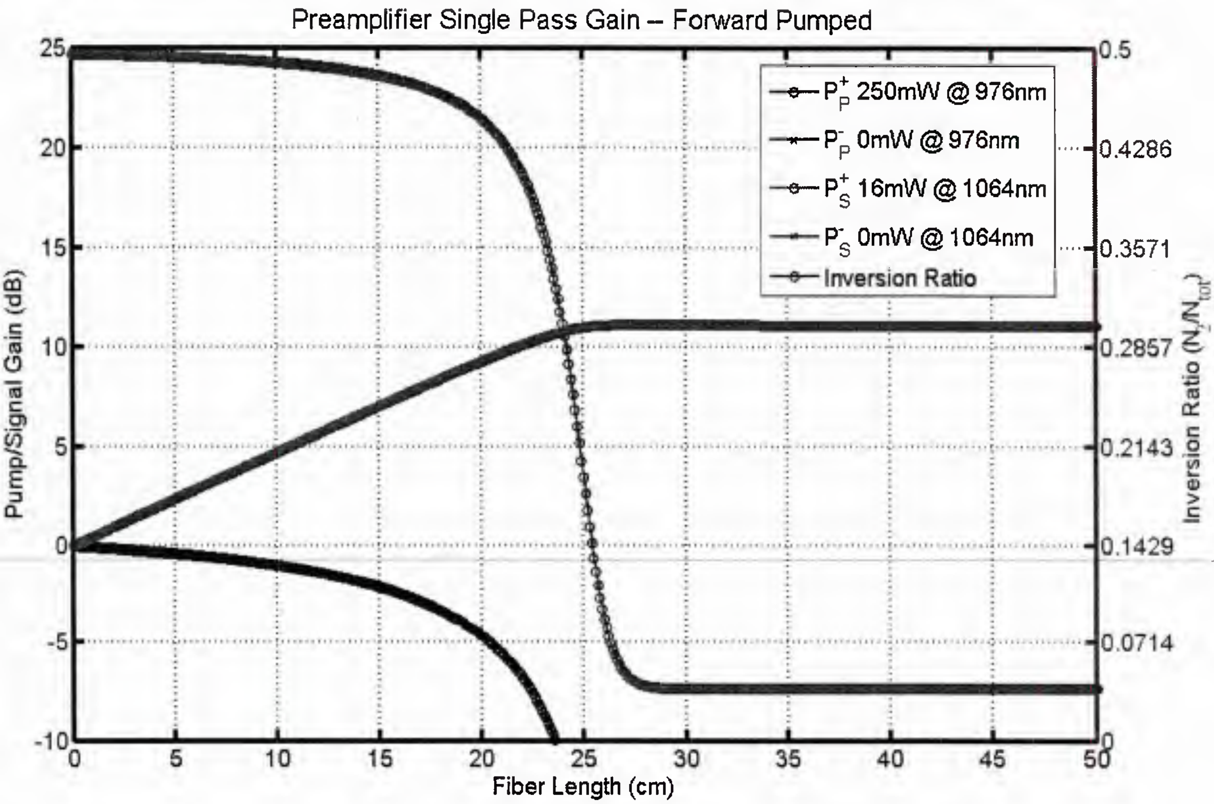

Figure 2. Simulated preamplifier performance. Using a 280 mW diode laser to core-pump Yb-doped fiber in a forward pumped, single-pass configuration results in an output signal of 200 mW.

Comparative performance simulations were run for several amplifier configuration options, varying the pump insertion location and the number of passes through the fiber. Each configuration is associated with different component losses, so the signal and pump powers at the input and output of the fiber also vary. Preamplifier signal and power inputs and outputs are shown in Table 2 for the simulated configurations, starting with the parameters listed in Table 1. Because it gives the highest output power, the forward pumped single-pass configuration was chosen for implementation. An optimized fiber length of 30 cm will be used, and a stage output of 200 mW is expected.

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Table 2. Preamplifier Configuration Comparison					
Configuration	**Pump Power to Fiber**	**Signal Power to Fiber**	**Signal Gain in Fiber**	**Signal Loss after Fiber**	**Signal Output Power**
	mW	**mW**	**dB**	**dB**	**mW**
Forward Pumped Single-Pass	250 (W)	16 (W/I)	11	0	198
Backward Pumped Single-Pass	250 (W)	16 (W/I)	11	0.5 (W)	177
Bidirectionally Pumped Single-Pass	225 (W/CP)	16 (W/I)	10.5	0.5 (W)	158
Forward Pumped Double-Pass	250 (W)	12 (W/I/CR)	12.5	1.5 (W/C)	148

Simulated insertion losses due to passive components are as follows:
CR: Circulator (1 dB); WDM: Wavelength Division Multiplexer (0.5 dB); I: Isolator (0.5 dB); CP: Coupler (0.5 dB)
Splice loss is assumed to be negligible (<< 0.5 dB)

The main gain amplifier was also simulated. The forward pumped single-pass configuration is the most efficient end-to-end, as in the preamplifier. Several different fiber sizes are commonly used in such amplifiers, so simulations were performed to predict output power for various sizes and various fiber lengths. Figure 3 shows that several fibers will produce the desired >11W output power in a reasonable fiber length. The 10/125 μm fiber size was chosen for use, because it allows low-loss splices to common single mode fiber component leads.

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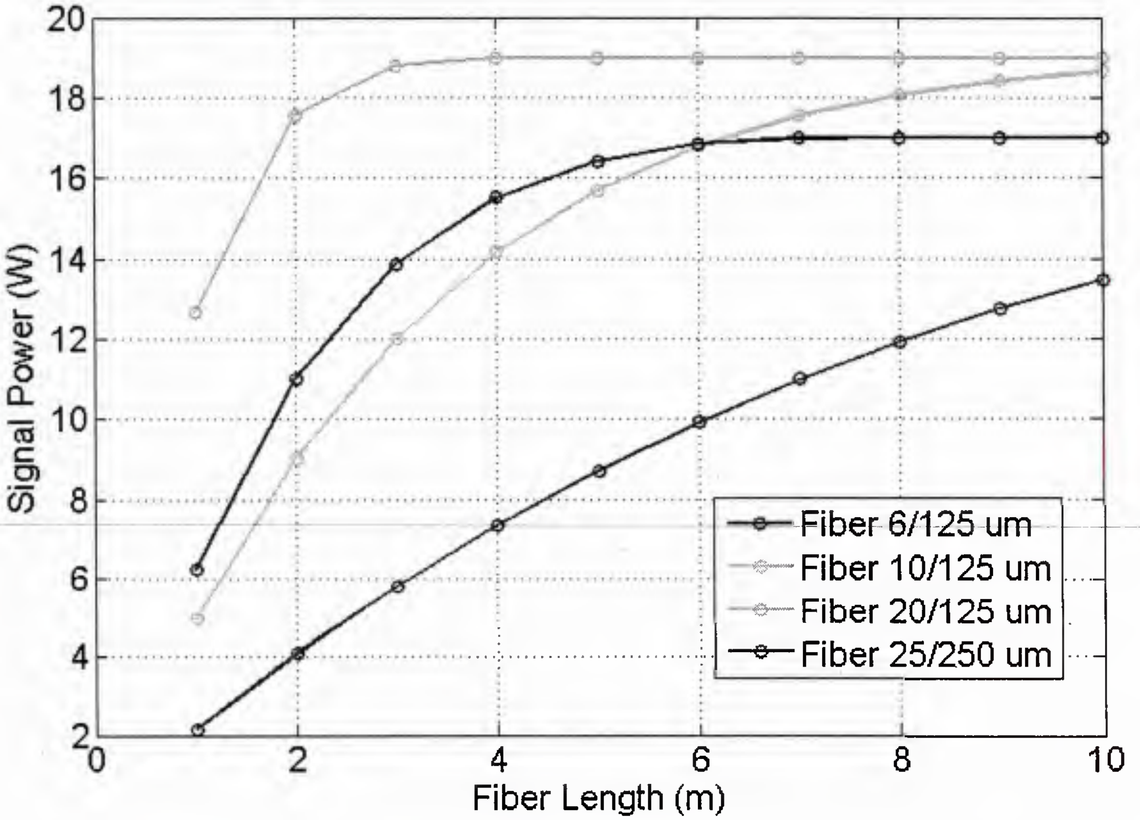

Figure 3. Simulated gain amplifier performance. Using a 20 W diode laser bank to cladding-pump Yb-doped fiber in a forward pumped, single-pass configuration. Output power varies according to fiber size and length.

The fiber laser and amplification stages are designed to match the constraints of the frequency doubling optical assembly. The collimating and focusing lenses were chosen for high laser intensity damage thresholds (LIDT). The SHG crystal itself has an efficiency curve as shown in Figure 4, so the gain amplifier is designed to provide 11 W to the crystal, for 1 W output. The crystal's bandwidth is limited to 0.1 nm, which is matched by the output grating of the fiber laser. The crystal will operate only on light whose polarization is perpendicular to its top surface, so linear polarization is enforced by the polarization controller after the preamplifier stage. Table 3 summarizes the predicted end-to-end performance of the system.

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Table 3. Power and Bandwidth Through System				
Component	**Input Power**	**Component Gain**	**Output Power**	**Component Bandwidth**
	mW	**dB**	**mW**	**nm**
Fiber Laser			20	0.1
Preamplifier Input Losses	20	-1	16	15
Preamplifier Active Fiber	16	11	200	200
Preamplifier Output Losses	200	0	200	15
Polarization Controller	200	0	200	-
Gain Amplifier Input Losses	200	-1	160	40
Gain Amplifier Active Fiber	160	17	12 W	200
Collimating/Focusing Optics	12 W	-0.5	11 W	5
SHG Crystal	11 W	-10.5	1 W	0.1
Collimating Optics	1 W	-0.5	900	5
System Output			**900 mW**	**0.1 nm**

System bandwidth is the minimum bandwidth of all components.

Summary

A high power frequency doubling circuit has been designed to deliver a high power, wide bandwidth green signal, which will be suitable for underwater LIDAR. All components have been matched and specified for this task. Simulations indicate that using the wide bandwidth fiber laser as an optical source, nearly 1 W of optical power at 532 nm can be generated, with 0.1 nm (18 GHz) of flat, chaotic bandwidth.

Short Work Statement for FY12 Q3.

The doubling circuit designed in FY12 Q2 will be implemented, and a high power, wide bandwidth green signal will be generated. Propagation in water will be tested, and system level experiments will be designed to test ranging performance.

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